Modelling and Simulation in the Autonomous Systems' Domain – Current Status and Way Ahead

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Abstract. A first Modelling and Simulation for Autonomous System Workshop (MESAS 2014) was organized by NATO Modelling and Simulation Centre of Excellence in Rome 2014. The main findings were related to the missing ontologies for AS deployment, a legal and cultural gap in the AS deployment and the request to launch the cross panel project under NATO Science and Technology Organization aimed at the AS development supported by modelling and simulation. The article is focused on the main findings form the 2015 edition based on the analysis of presented papers and final panel discussion in the workshop. The experimental frameworks for the AS development and deployment is mentioned and its perspective as well. The next part is explaining the differences in the autonomous system and human behavior modelling. The last part is focused on the AS concept of operation and the potential consequences.

Keywords: High Level Architecture · Autonomous System · Operational field · Modelling and simulation · Experimental framework

1 Introduction

Modelling and Simulation to support development and deployment of systems with autonomous capabilities proved to be valid concept during the 2014 Modelling and simulation for Autonomous Systems workshop [1]. 50 papers were submitted and 32 were later included into the proceedings. The main aspects touched by proceedings and by the final round about discussion session were the technology progress of the unmanned systems, a need for the common vocabulary to be shared between Autonomous System and Modelling and Simulation domains and the cultural and legal gap in the Autonomous System operational deployment. Among others the need to create cross panel activity under the NATO Science and Technology Organization (STO) was identified. STO is currently composed of more than 3500 Scientists and Engineers from NATO and its partners working on approximately 140 research activities. Autonomous System (AS) concept, design and implementation are covered by System Analysis and Studies (SAS) panel. M&S as a scientific discipline is under governance of NATO M&S Group (MSG) panel.

Where we have moved in these specified areas after one year?

In spite of the identified gap, missing the AS ontology to be used in the Modelling and simulation domain, no effort has been identified. AS ontologies or taxonomies are

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being heavily developed without taking into an account the need to reflect it both in the operational and technical field and importance of shaping it based on the M&S aspects as well. As an example of such approach that defines the AS ontology technologically oriented without touching the operational portion and M&S domain is in [2]. The result is that in the Modelling and Simulation domain the main taxonomy is based on the distributed simulation standards like DIS, HLA [4, 5] and still doesn't reflect the need to incorporate the autonomous domain in. On the other hand, vice versa, the AS taxonomy and ontology doesn't contain natively modeling and simulation aspects and therefore the experimentation cannot effectively and unanimously employ the M&S. One of the proposed actions might be a new working group under the STO composed of the member from the SAS, MSG and Human Factors and Medicine (HFM) panel. The last one, HFM, is critical for success. The human behavior specialist must be part of the ontology/taxonomy design; otherwise the objective to reproduce the human behavior in the AS will not happen. HFM, should as well clarify the role of the public opinion in the AS operationalization.

The last year MESAS motto picture, Fig. 1, defined the cultural gap between Systems with limited Autonomous Capabilities and System with autonomous Capabilities or Fully Autonomous System. The gap was explained as a fear of systems without human in the loop and potential consequences.

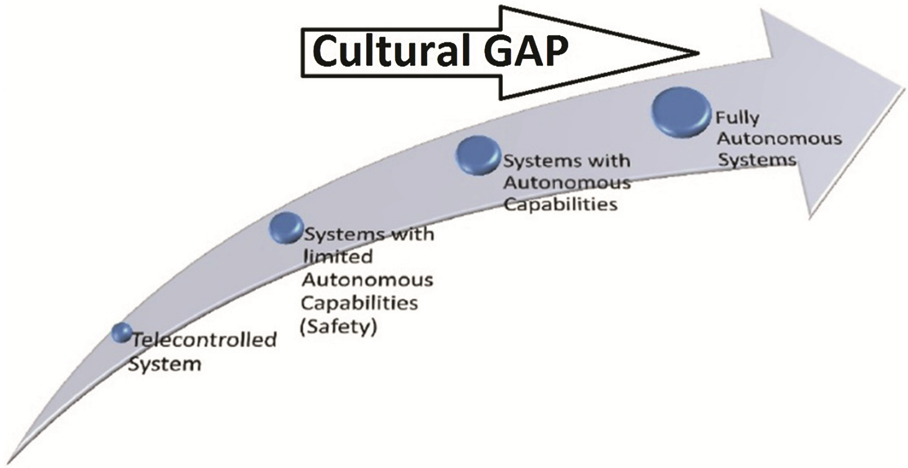

Fig. 1. AS technology progress dimension and cultural gap (NATO M&S COE source)

This year a gap was slightly modified based on the fact that in some areas the systems with full autonomous capabilities are already operational. As an example, the train control without conductor; human in the loop; might be taken. Therefore the issue of a cultural gap seems to be overcome; not it is moving into the psychological domain. We are refusing the employment of AS in the air domain without being able to accept in our minds that in some areas AS are regular part of our life.

Legal gap was identified last year and it remains on the list. After one year there is still missing a clear AS policy or legal documents, or even the same terminology that might be used by lawyers when justifying/banning the need for AS. An importance of public opinion involvement into the discussion about AS was identified to overcome the gap. It is not anymore sufficient to employ into discussion only classical triangle - Military, Industry and Academia (MIA), but a Public (P) should be integral part of it. We are speaking about MIAP square of community of interest around AS.

The technology progress dimension is not the only one that is comprised by the AS paradigm. The level of autonomy is another one and level of collaboration between AS is the third dimension. These findings are reflected in the Fig. 2.

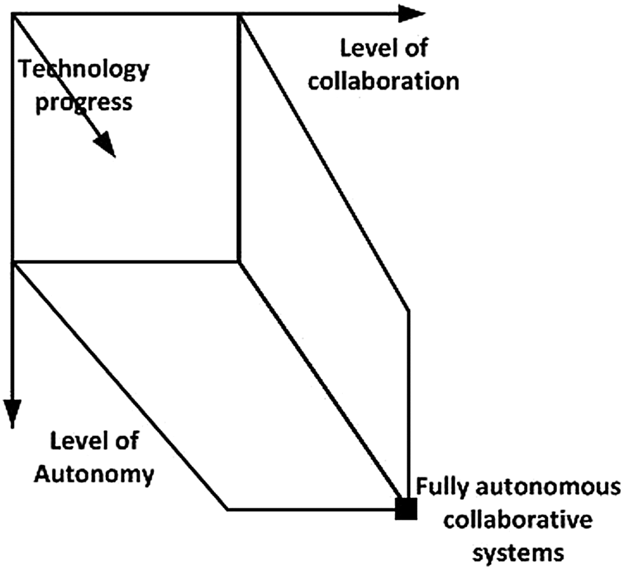

Fig. 2. Three dimensions of AS paradigm (author's source)

Technology progress is a main driver to reach the status of fully autonomous system with collaborative behavior being employed in the battlefield. The main obstacles to reach such state is legal/psychological gap identified earlier and the computational limits of current methods used to implement AS.

2 Experimental Frameworks for Autonomous Systems

To test, evaluate, analyze and optimize AS behavior and cooperation in the operational field, M&S experimental frameworks plays the most important role [1, 3]. The general experimentation AS framework uses as a backbone distributed simulation environment with support of distributed simulation standards like DIS, HLA and DDS [4–6]. The main actors of the M&S experimental frameworks are following:

- Combination of physical and virtual replications of entities
  - Human Operator/Being,

  - C2 system,
  - Communication node,
  - AS.
- Combination of physical and virtual Environmental features
  - terrain,
  - atmosphere,
  - weather,
  - etc.

Lack of single standard for data exchange mechanism in the experimental frameworks corresponds to the current status in the distributed simulation domain. Experimental frameworks are usually design to natively support only one of the aforementioned standards which complicates the way of its reuse and double use [1].

Another challenge in the M&S experimental frameworks is different requirements for quality and granularity of environmental data from each replicated entity point of view. Demand on having micro and macro environmental data about operational area is computationally very demanding.

The M&S experimental frameworks from the future perspective require following interfaces:

- Human machine interface,
- C2 interface,
- Weapon systems interface,
- Unified interface to the knowledge management systems,
- Real time operational interface for scenario development, description or replication.

Operational interface is currently not developed topics. Without permanent connection to the C2 system and all sensors on the battlefield it is complicated to optimize the cooperation and collaboration of AS and human being to achieve particular mission objective. The operational scenario must be replicated in the synthetic environment comprising all physical and virtual entities. Based on real data a mission rehearsal and planning of AS and human being resources might be done effectively.

3 AS Behavior Modeling Versus Human Behavior Modelling

Do we need to model AS behavior? Current approach in the experimental frameworks is based on the idea of using the autonomy algorithms for simulation as well as the real world environment. Therefore if a universal native API is available, than there is no need to reinvent model of AS. The core AS behavior would be transferred from and to virtual/real AS by employing simple copy and paste technique. Moreover developing special AS behavior model cannot reveal any new findings from the system point of view. AS just reflects execution of an algorithm. It doesn't pose any human being creativity and only follows code instructions. Attempt to bring closer the creativity to the AS is clashing with the proven theory of Algorithmic Information Theory [7].

However to study and implement model of AS cooperation and collaboration is useful. If AS, represented by system of systems, cooperate and collaborate each other, the simulation study might reveal AS parameters, optimal algorithms and techniques to be implemented in the operational environment.

4 Algorithms for the AS

Algorithms for autonomous system correspond to the functionalities provided by it. One of the algorithms' classifications might be done based on the cooperative subsystem of AS and external factors:

- algorithm for AS sensors, like Light Detection and Ranging (LIDAR) [8], IMU Inertial Measurement Unit (IMU) [9];
- multi sensor data fusion algorithm [10];
- machine learning/motivated learning for building knowledge database of meta modeling data to assure the object recognition [11];
- mission [12], global [13] and local planning algorithm [14];
- cooperative algorithm [15].

The domain of the collaborative algorithms between ASs and AS and human being as well is the most important and not yet solved from the operational point of view. It goes behind the idea of cooperation; the common planning is not sufficient anymore. It contains algorithms that are able to share the real time battlefield picture and based on its understanding make a collaborative decision resolved in action plan.

Another critical and not developed algorithms' domain is focused on the reliability and robustness of the solutions that might be targeted in the near operational future. Diversity of field conditions causes AS performance failures. Therefore the next AS generation must primarily touch the issues of a failure detection and recovery. It is the only way to come closer to the fully autonomous system or at least to minimize human supervision on unmanned systems.

Another critical factor in the successful implementation of AS is to develop algorithms for reliable communications and redundant sub systems or systems. Without having in place such robust algorithms, the cooperative and collaborative algorithms would not be applicable.

Among other an issue related to the implementation of ethical features into the AS is appearing. A need to implement algorithm, ethical adaptor, being able to proactively modified behavior of AS similar to the human moral emotion, is crucial to enable fully operational deployment of AS [16]. Therefore there is a clear indication of moving towards the cognitive algorithms domain. Main focus is classification of dangerous local AS behavior and selection of a better one to fulfil the global objective.

Algorithms carrying out the building of knowledge database should use the big potential of gaming environment. Online gaming engine might be used to collect behavior of players trying to cooperate and collaborate and may define the behavioral patterns for AS collaboration in the operational environment. It is one of the ways to increase the quality of knowledge database system used for AS decision making.

5 Concepts of Operation

M&S is playing the most important role in pre-deployment phase of collaborative AS into the battlefield. We still do not cover perfectly the potential of isolated AS being deployed. The collaborative AS in the battlefield opens a new era of operational use. M&S via an experimental framework might clarify effectiveness of using collaborative fully autonomous systems versus highly automated systems or their mixture. Moreover massive using of the MS experimental framework for AS collaboration might overcome the psychological block to trust AS. Experimental frameworks employment might define limits of AS deployment and increase a trust in AS.

Important aspect is to use experimental frameworks to train trainers. Trainer is in charge of supervision of deployment of cooperating not fully ASs. Trainer must be able to recognize that ASs are still cooperating in the correct way, not modifying their behavior in the way not to reach the global objective. It opens a new market for training system.

Methods of Verification Validation and Accreditation for ASs and for their cooperation and collaboration must be developed to build up an operational trust. Experimental frameworks are not unified and validation data set is not yet defined. First approach might be to define the best practice for the M&S experimental frameworks for AS and to define standard set of scenarios. Effectiveness of AS cooperation and collaboration might be validated against it. Such a set of scenarios might define acceptable conditions of AS operational use from public opinion point of view.

For a concept of operation of AS, it is important to create such taxonomy of AS that connects level of autonomy and the functional capabilities of ASs seen as an individual system and/or as cooperative entities as well. There should be an explicit definition of AS capabilities in the perspective of a particular level of autonomy.

Big issue still to be solved in the domain of fully ASs collaboration is the liability. Who will be responsible for course of action, if there are casualties because of failure of fully collaborative ASs. If there is not man in the loop, no one is liable for the collaborative decision.

6 Conclusion

M&S is playing the crucial role in the integration phase of ASs into the operational field. Therefore, the differences between fully autonomous system and highly automated AS are revealed with the perspective of its operational use. AS vitally needs to be connected to the knowledge management system. From that perspective there is a requirement to define unified interface between AS and knowledge management system to allow AS to get data, analyze it adopt it and make decision. Taxonomies and ontologies of AS are still not well defined. Critical is to use the common vocabulary in interdisciplinary use of AS and M&S and to model and implement collaborative algorithms between ASs and AS and human being. Using the identical algorithms for AS development in the physical and synthetic domain would assure decreasing cost of AS deployment. Liability of decision done by collaborative fully ASs without human in the loop must be solved very soon to enable its operationalization.

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